

****TITLE****

*ASP Conference Series, Vol. **VOLUME**, **PUBLICATION YEAR***

****EDITORS****

The Wisconsin H-Alpha Mapper Northern Sky Survey

G.J. Madsen, L.M. Haffner, & R.J. Reynolds

*Dept. of Astronomy, University of Wisconsin – Madison, 475 N.
Charter Street, Madison, WI, 53706-1582*

Abstract. The Wisconsin H-Alpha Mapper (WHAM) has completed a one-degree resolution, velocity-resolved northern sky survey of H α emission from our Galaxy. The unprecedented sensitivity of the instrument and accurate spectral subtraction of atmospheric features allow us to detect Galactic features as faint as 0.1 Rayleighs ($EM \approx 0.25 \text{ cm}^{-6} \text{ pc}$). This survey allows a direct comparison of the ionized and neutral components of the ISM on a global scale for the first time. All-sky maps of H α emission in select velocity bands highlight the rich kinematic structure of the Galaxy’s ionized gas. The full set of data from the WHAM survey is now available at <http://www.astro.wisc.edu/wham/>.

One surprising result is that the high latitude sky of both the ionized and neutral components display marked similarity in the location and radial velocity of emitting regions, especially for many of the previously identified intermediate velocity clouds. Although there is evidence for spatial and velocity correlation, in many cases examined so far there is little evidence for a quantitative correlation between the column density of H I and the emission measure of H II.

WHAM is also capable of studying the ISM through optical emission lines other than H α . Two directions toward the Perseus arm have been studied in detail through several other optical emission lines. The multiple velocity component structure toward these directions provides a selection of ionized environments for study and shows interesting variations in the ratios of these lines. WHAM also has the ability to study select regions of the sky at high spatial resolution ($3'$ to $5'$) with high velocity resolution. Such observations will allow an even closer comparison between the neutral and ionized components with the advent of high resolution H I surveys.

1. Introduction

The WHAM instrument is a fully remotely operated facility with a 15 cm, dual-etalon Fabry-Perot spectrometer at the focal plane of a 0.6 m telescope atop Kitt Peak in Arizona (Reynolds et al. 1998). The WHAM spectrometer has a 1° diameter circular field of view on the sky, and a velocity resolution of 12 km s^{-1} within a 200 km s^{-1} wide spectral window that can be centered on any wavelength between 4800 \AA and 7300 \AA . WHAM was designed to detect very weak emission lines from ionized gas.

The Wisconsin H-Alpha Mapper Northern Sky Survey (WHAM-NSS) is the first deep, velocity-resolved survey of interstellar H α emission over the northern sky ($\delta \geq -30^\circ$). The survey consists of 37,565 individual observations taken over a span of two years. Each observation recorded the composite spectrum of a one-degree diameter patch on the sky. The spectral resolution of 12 km s^{-1} made it possible to separate cleanly the interstellar emission from the terrestrial emission in every spectrum and to measure the thermal and non-thermal motions of the interstellar gas. Details about the WHAM-NSS and downloadable versions of the survey can be found at <http://www.astro.wisc.edu/wham/>.

These survey maps of interstellar H α emission provide the first global view of the distribution and motions of wide spread ionized hydrogen within the Milky Way (see Figure 1). The small bright knots of H α are classical emission nebulae in the vicinities of hot O and B stars located mostly near the Galactic midplane. Between these bright knots and filling most of the sky is fainter H α emission from the Warm Ionized Medium (WIM), with a characteristic temperature $T_e \approx 10^4 \text{ K}$ and density $n_e \approx 0.1 \text{ cm}^{-3}$.

Past studies have shown the WIM to be a significant component of the interstellar medium, especially in the halos of disk galaxies. In the Milky Way, the WIM has a mass surface density about one-third that of neutral atomic hydrogen, a power requirement equal to the kinetic energy injected into the Galaxy by supernovae, and a characteristic scale height above the midplane of 1000 pc, approximately five times larger than that of the neutral hydrogen. This survey of the WIM shows rich structure both on the sky and in velocity, allowing an exploration of the origin of the ionization and heating of this gas and its relationship to the other components of the interstellar medium.

2. High Latitude H α Emitting H I Clouds

The intermediate velocity channel maps ($-75 \text{ km s}^{-1} \leq v_{LSR} \leq -50 \text{ km s}^{-1}$) from the survey reveal significant amount of high-latitude H α emission. Much of this emission is located near HI gas previously identified and classified as Intermediate Velocity Clouds (IVCs; see the recent compilation by Wakker 2001). One particularly striking example is the IVC Complex K, reported by Haffner, Reynolds, & Tufte (2001).

They find that general spatial correlation between N_{HI} and H α contours, and an excellent kinematic correlation between H α and H I spectra toward Complex K, demonstrating that they probe the same structure. However, the spatial intensity distribution of the lines does not appear to be related, i.e. peaks in H I emission do not necessarily correspond to peaks in H II emission. This is consistent with photoionization by an external flux of radiation. In this case, the H α intensity is determined by the incident flux and is unrelated to the H I column density of the cloud whose outer surface is being ionized.

WHAM has also recently observed very faint H α emission associated with the northern tip of the Magellanic Stream. In all five lines of sight observed, we find H α emission at the same velocity as the H I gas with intensities ranging between 0.05 - 0.1 R ($\text{EM} \approx 0.1 - 0.2 \text{ cm}^{-6} \text{ pc @ } 10^4 \text{ K}$). Such observations are critical for our understanding of high and intermediate velocity clouds, including

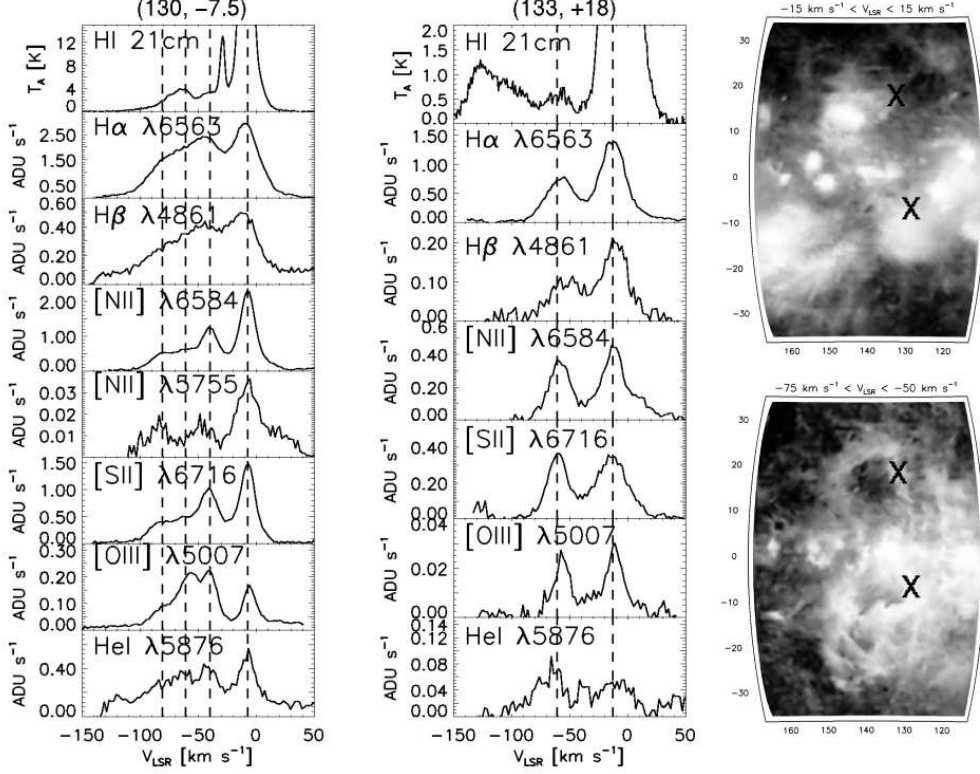


Figure 1. Multiwavelength spectra (left) and $H\alpha$ survey images (right) from WHAM. The spectra toward the two directions labeled by their titles are marked by an 'X' in the images on the right. Note the variations in the line ratios among the velocity components outlined by the dashed vertical lines in the spectra. The images on the right are two different velocity channel maps of the same region of the Galaxy, sampling local gas (top) and more distant Perseus arm gas (bottom).

the ability to constrain models of the escape of Lyman continuum photons from the Galactic disk (Bland-Hawthorn & Maloney 1999).

3. Probing the Heterogeneous Nature of the WIM

The WHAM Northern Sky Survey has revealed the presence of remarkable large-scale, $H\alpha$ -emitting structures, including loops, filaments, bubbles, and bright “point sources” throughout the WIM superposed on a more diffuse $H\alpha$ background (e.g. Figure 1). With the completion of the survey, WHAM can now be used to study the WIM through observations of several other optical emission lines, probing the physical properties of the gas, and with higher angular resolution imaging, exploring its smaller scale structure.

Figure 1 shows the spectra of sight lines towards $l = 130^\circ, b = -7.5^\circ$ and $l = 133^\circ, b = +18^\circ$, sampling filamentary and diffuse gas. The data are given in units of arbitrary flux versus LSR velocity. Figure 1 also shows two velocity

channel WHAM-NSS maps towards these directions, chosen to isolate the local gas near the LSR and the more distant gas in the Perseus arm near -60 km s^{-1} . The 0 km s^{-1} frame is dominated by diffuse ionized gas on which is superposed large, low density O and B star H II regions. The large “bowtie” in the Persues arm frame is believed to be a superbubble blowout associated with the Cas OB6 association and the H I Normandeau “chimney” (Reynolds, Sterling & Haffner 2001; Normandeau, Taylor, & Dewdney 1996).

The spectra reveal multiple emission line components in each direction, interpreted as local gas, Perseus spiral arm gas a few hundred parsecs above the midplane at a distance of 2-3 kpc, and higher velocity gas at even greater distances. We find significant variations in the ratio of these emission lines among the different radial velocity components along a single line of sight, as well as between the two lines of sight. Preliminary analysis reveals interesting correlations and anti-correlations among the line ratios and raises new questions about the heterogeneous nature of the WIM. Analysis of the strength of these emission lines and their ratios reveal important clues about the temperature and ionization state of the WIM, and indirectly reveal information about the ionizing spectrum, extinction, density, and heating of the gas (Haffner, Reynolds, & Tufte 1999; Reynolds, Haffner, & Tufte 1999). We also find ionized gas associated with each of the warm H I components toward $(130, -7.5)$, but not with the cold H I feature near -30 km s^{-1} . These observations can be used to explore how the physical conditions in the WIM change with morphology, and how they compare with classical H II regions.

Another new tool available with WHAM is higher angular resolution imaging. With the insertion of a set of optics, WHAM can obtain very narrow band, $3'$ resolution images of the sky within its 1° beam. An adjustable iris mechanism in the imaging optics can set the width of the narrow spectral window of the image between 15 km s^{-1} to 200 km s^{-1} . The combination of the multiwavelength observations of various diagnostic emission lines with the higher angular resolution imaging will allow us to learn more about the elusive nature of this important phase of the interstellar medium. The WHAM Survey has already revealed the rich spatial and kinematic structure of the warm ionized medium. These multiwavelength and higher spatial resolution observations will hopefully shed additional light on fundamental questions pertaining to the nature of the WIM and no doubt will raise even more questions. This work was supported by National Science Foundation Grant AST96-19424.

References

- Bland-Hawthorn, J., & Maloney, P.R. 1999, *ApJ*, 510, L33
- Haffner, L.M., Reynolds, R.J., & Tufte, S.L. 1999, *ApJ*, 523, 223
- Haffner, L.M., Reynolds, R.J., & Tufte, S.L. 2001, *ApJ*, 556, L33
- Reynolds, R.J., Haffner, L.M., & Tufte, S.L. 1999, *ApJ*, 525, L21
- Reynolds, R.J., Sterling, N.C., & Haffner, L.M. 2001, *ApJ*, 558, L101
- Reynolds, R.J., Tufte, S.L., Haffner, L.M., Jaehnig, K., & Percival, J.W. 1998, *PASA*, 15, 14
- Normandeau, M., Taylor, A.R., Dewdney, P.E. 1996, *Nature*, 380, 687
- Wakker, B.P. 2001, *ApJS*, 136, 463